ANALYSIS OF CALIFORNIA HIGHWAY PATROL TELECOMMUNICATIONS SYSTEM REQUIREMENTS

Wesley Harold Moore

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

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by

Wesley Harold Moore

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A description of the existing organization and systems and an introduction into those aspects of telecommunications system analysis which are applicable to CHP requirements are given. As a result of this preliminary analysis it is concluded that the communications network need not follow the line

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In this thesis, management policy makers are introduced to those parameters effecting telecommunications system design. In addition, it provides guidance to designers and analysts for the development of a CHP telecommunications system to supercede the existing one.

Analysis of California Highway Patrol

Telecommunications System Requirements

by

Wesley Harold Moore
Lieutenant, United States Navy
BSEE, University of Idaho, 1969

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I. INTRODUCTION

The California Highway Patrol, CHP, maintains a telecommunications network with the dual purposes of interfacing with the California Law Enforcement Telecommunications System, CLETS, for accessing law enforcement data bases and of providing a means for exchanging administrative messages. Due to the staffing of the Communications Section of the CHP, most system design and analysis is done by the operator of the system, Pacific Telephone Company, under contract from CHP. The result is a system which satisfies CHP requirements as understood by the contractor but is not necessarily the best that modern telecommunications can provide.

At the outset, it was the intent of the author to utilize the basic data available concerning network operation to determine the parameters of an optimum telecommunications system for the California Highway Patrol, However, the basic data did not exist or was not available to the author. Pacific Telephone Company data was totally inadequate for such purposes.

Data collection by Pacific Telephone is conducted in the following manner. Quarterly, data collectors are dispatched to the various switches in the CHP system for a 48-hour period. This period is determined to be the busiest of the quarter through narrative inputs from the users. The data collectors use counters to accumulate the time each circuit is used and the number of calls made or attempted. From this data, peak load periods are identified and only those figures

for the peak hour, eight-hour shift and 24-hour period are retained. These figures are compared with tables derived from models of similar systems created at Bell Labs. These tables define load thresholds at which extra lines are required, but the overall load distribution is not considered. It is possible that an administrative action such as excluding administrative traffic from the network during certain periods would eliminate this peak, and thus the need for an extra line. It is the purpose of this thesis to define and discuss alternative means of determining network requirements and network organization.

Chapter II of the thesis describes the existing CHP organization, the California Law Enforcement Telecommunications System, the Pacific Telephone Company switch designed for law enforcement data exchanges, and the CHP telecommunications system. Chapter III discusses the various aspects of systems analysis as they relate to telecommunications. Included in this chapter are discussions of data requirements, response time determination, terminal characteristics and distribution, and network control and organization. Finally, conclusions and recommendations for implementing these techniques in the development of telecommunications system for CHP are described in Chapter IV.

II. EXISTING ORGANIZATION & SYSTEMS

A. CALIFORNIA HIGHWAY PATROL (CHP) ORGANIZATION

The California State Legislature created the California Highway Patrol as a division of the State Department of Public Works in August, 1929. The Patrol at that time had 280 men and was equipped with 225 motorcycles and 80 automobiles, mostly roadsters. The goal of this statewide organization was to provide a uniform policy of traffic law enforcement.

The Highway Patrol was transferred from the Department of Public Works to the Department of Motor Vehicles in 1931. In 1947 it became a seperate Department of the state government and is now a part of the Business and Transportation Agency. At the end of 1973 the CHP had 5524 uniformed patrolmen and was equipped with 2020 sedans, 390 motorcycles, three helicopters and three fixed-wing, short take-off and landing aircraft.

The purpose of the CHP is to perform those functions and services which will assure the safe, lawful, rapid and economical use of the 97,630 miles of the State Highway system for which it has patrol responsibility. Highway safety has been the primary goal and mission of the CHP since it was established in 1929.

The CHP is divided into seven zones for administrative purposes and the zones are further divided into 87 areas. The zones headquarters are located in Redding, Sacramento, San Francisco, Fresno, Los Angeles, San Diego, and San Luis Obispo. This zone and area organization forms the line organization under the Deputy Commissioner.

The Assistant Commissioner serves as Chief of Staff and heads the support staff which consists of the Administrative Services Division, Operational Planning and Analysis Division, Safety Service Division and the Training Division.

Data communications within the CHP falls within one of two categories; either administrative communications among the various units and agencies of the department or law enforcement data communications with CLETS. It is very significant to note that administrative traffic need not, and in fact usually does not, follow the line or staff organizational structure. The fact that a station is a zone headquarters does not influence, to any significant degree, the administrative message load of that station.

Law enforcement data communications may originate with or be addressed to any CHP organizational unit. The primary users of this type of data are the patrol officers in the field and, therefore, those CHP units which serve as major dispatch centers handle the majority of all law enforcement data.

The two different categories of data necessitate different handling procedures and communications system performance characteristics. Law enforcement data generally originates with a patrol officer in the field who requires prompt and accurate information. This type of data is handled by pro-forma messages over priority circuits to computerized data bases. Administrative communications are generally used where speed is significant only to the extent that other methods of delivery (mail, courier, etc.) are too slow and a written record of the communication is desired. These messages are in any format with only the heading containing message accounting information being in a specified format.

B. CALIFORNIA LAW ENFORCEMENT TELECOMMUNICATIONS SYSTEM (CLETS)

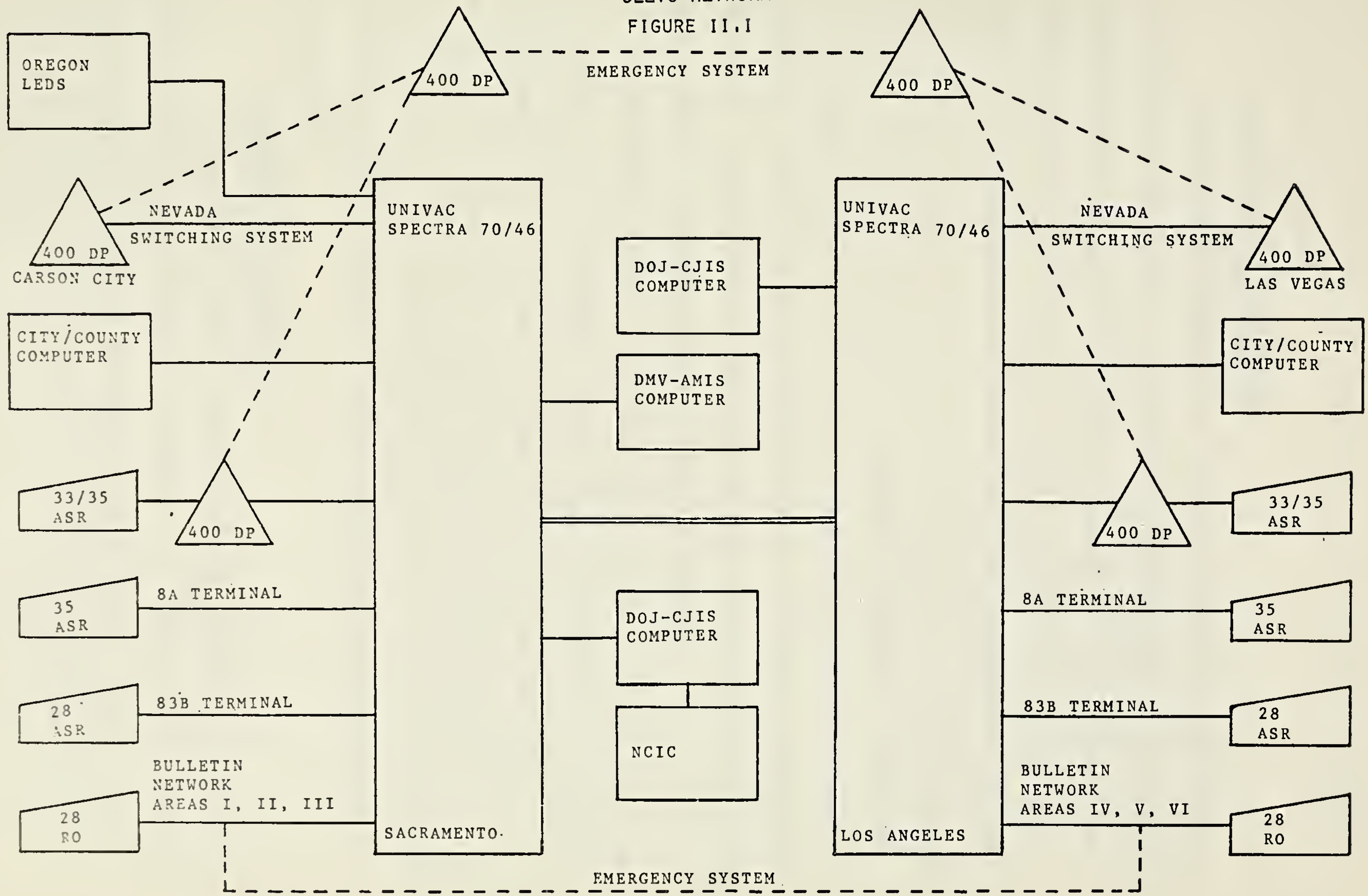
1. Introduction

The California Law Enforcement Telecommunications System (CLETS) is a high-speed message switching system, fig. II.1, which allows any urban or rural law enforcement agency to obtain instant information on wanted persons, stolen and lost property, firearms, and stolen vehicles. CLETS was created by an act of the 1965 California State Legislature and became an operational system in April, 1970. It is the result of four and one-half years of study and design by a committee composed of representatives of the California Peace Officers Association, the California Sheriff's Association, the League of California Cities, the County Supervisors' Association of California, officials of various State agencies, and vender personnel.

The system links California law enforcement agencies to computer data bases at the California Department of Justice headquarters, the California Department of Motor Vehicles, and the National Crime Information Center in Washington, D.C. With CLETS, an officer in the field can quickly make a status check on firearms, property, vehicles, or persons. The officer radios an inquiry to his dispatcher who prepares and transmits a coded inquiry to CLETS. The CLETS computer routes the inquiry to the appropriate data base and, in certain cases, to the FBI's National Crime Information Center data bases in Washington, D.C. CLETS transmits the results of the inquiry to the dispatcher who radios the information to the officer who initiated the inquiry. Thus, in just a matter of seconds, the officer in the field

CLETS NETWORK

FIGURE II.I



knows if he should release the individual, take immediate action, or call for assistance.

2. Functional Configuration

Due to the geographical layout of the state of California and its population distribution, the communications needs of the State have been divided into northern and southern areas. Two UNIVAC Spectra 70/46 computer systems in Los Angeles and two Spectra computer systems in Sacramento (one Spectra 70/26 and one Spectra 70/60) act as message switching centers for a communications network linking more than 450 terminal locations throughout the State. All station arrangements, sub system net-works, and data base computers are connected to one of the two switching centers. The two centers are connected to each other via voice grade (2400bps) lines which facilitate rapid transfer of messages throughout the network.

The administrative and broadcast networks serve more than 900 teletypewriter terminals. Any station can send direct, point-to-point messages to any other terminal in the system and is able to access the files of five data base systems containing approximately 37 million stored files. A user may query the system for a record and receive a response within seconds or he may update the files directly from his terminal.

3. Administrative Network

This network is used by subscribing agencies to transmit and receive normal point-to-point messages. Terminal users connected to the switching computers have the capability of sending to another station or several stations at once via a miltiple address feature.

Terminal operators must follow certain formats which enable the message switching program to validate the message and to determine the correct routing of the message.

4. Data Base Systems

While performing its function as a message switching system, CLETS also serves as a vehicle for an inquiry/response and data collection system. Inquiries from user terminals are processed according to established priorities which insure prompt response to the user. The system of interfaced data bases consists of the California Department of Motor Vehicles file system, the California Department of Justice Criminal Justice Information System (CJIS), and the Federal Bureau of Investigation National Crime Information System.

The Department of Motor Vehicles maintains a computerized file of all vehicle registrations and driver licenses for the State of California. The CLETS interfaces with this file system and can retrieve all records filed either by name, driver's license number, vehicle license number, tag number or registration number.

The Criminal Justice Information System is actually a family of on-line, real-time systems described below.

a. The Wanted Persons System (WPS)

The WPS assists local law enforcement agencies in locating and apprehending persons implicated in crimes. This program provides timely information to all agencies concerning persons for whom a warrant has been entered into the system.

When an agency issues a warrant for arrest, the subject's name and description, reasons for the want, agency involved, and

other pertinent data may be entered into the data base file. This information is immediately available to any authorized agency upon inquiry to the system. The primary indices used to access the file are name and date of birth, Criminal Identification and Investigation (CII) number, social security number, and California driver's license number.

b. The Automated Property System (APS)

The APS serves as a single record keeping source for miscellaneous property information in order to recover and return lost or stolen personal property to the owner and to provide investigative leads for the apprehension of criminals. The Miscellaneous Property File contains records describing law enforcement status records (stolen, lost, found) and pawns.

c. The Automated Firearm System (AFS)

The AFS provides local law enforcement agencies with firearm status information through a central record file of firearms purchased, stolen, lost, found, and pawned. A record of persons who purchase firearms is maintained in order to prevent individuals specified by law (aliens, drug addicts, criminals, juveniles, and persons with a history of mental-illness) from acquiring concealable weapons. This readily available information provides investigative leads in the recovery of lost and stolen firearms and the apprehension of criminals.

d. The Stolen Vehicle System (SVS)

The SVS makes available a readily accessible central source of information concerning vehicles which have been lost, abandoned, stolen, found, stored, or impounded. This program

provides rapid indentification and location of vehicles connected with crimes or wanted by justice agencies for other reasons.

e. The Criminal History System (CHS)

The CHS represents a method of maintaining complete, up-to-date information on active criminals including past activity within the justice system, and of delivering this information as rapidly as necessary. The data base in divided into two basic areas: Personal data, which serves to identify individuals who are known to the system; and criminal history, which includes a record of CJIS cognizant charges and disposition including dates and pertinent agencies. Supporting the data bases are several indices to allow automatic inquiries into the files.

The National Crime Information Center data bases consists of nearly five million files. The categories of information included in the data base are: Wanted persons; stolen/felony vehicles or boats; stolen/missing license plate numbers; stolen articles; stolen/missing or recovered firearms; stolen/embezzled/counterfeit or missing securities; and criminal histories. Each of the CJIS systems interface with the NCIC to provide CLETS users with the capability to utilize NCIC facilities. Inquiries are transmitted to NCIC from CLETS via 2400bps lines for electronic processing and communications network delivery of responses. The NCIC is utilized if no response occurs as a result of a CJIS base search or upon request the user signified by use of a special inquiry header format. The user has the option of entering and updating data in NCIC files with the exception of CHS. Criminal history data can only be updated by terminals located in the

State Department of Justice to insure that the information being entered has been verified and is accurate.

5. Broadcast Network

The State of California is divided into six areas for broadcast (all points) messages. The broadcast network is composed of six non-selective simplex line arrangements of receive only teletypewriters. Each message switching center services three of these lines which, in turn, service the northern and southern regions of the State. The system can send a message to any combination of the six areas simultaneously.

6. Message Processing

Upon receipt of a message from an outlying terminal, the switching system validates the message and either accepts or rejects the message. If the message is accepted, it is stored on disc and an input journal is written on disc and tape. If the message is rejected by the validation program, an error message will be produced.

Priorities determine the output transmission order of messages. The system aligns messages according to a prearranged priority scheme. Responses to inquiries and certain service messages are assigned a higher priority than normal point-to-point transmission. The highest priority is reserved for law enforcement emergency messages.

When the receiving terminal is free to accept a message, the CLETS computer reads the message from its disc storage, appends the sequence number and time stamp to it, and transmits the message to the proper station. When these procedures are completed, an output journal is recorded on tape and disc, along with the appropriate

time stamp. Although the message has been transmitted, its image remains in the general disc queue for approximately 24 hours to accommodate on-line retrieval requests.

7. Software

Private consultants, under a contract with RCA, were the prime contracted for CLETS software development. The software team, which included some of the foremost communication software experts in the nation, expended approximately 20 man years in the development of CLETS software. The system includes all features of a modern message switching system and interconnects a variety of terminals and computer systems. Advanced features include automatic switching to back-up hardware components in case of hardware failure. The design goal of the system was to switch approximately 17,000 messages per peak hour, to provide 24 hour retrieval capability, and to be operational 24 hours per day, seven days per week. A substantial number of additional messages are generated internally in the system because of the need to send messages between centers and to issue notices to the monitor terminals. Average message length was established as 170 characters with no upper limit on the message size. Approximately eighty percent of the total traffic generated is inquiries from a field terminal to one of the data bases at Department of Motor Vehicles or the Department of Justice. The design goals were intended to provide expected growth through 1977.

The CLETS message switching system runs under the standard RCA TDOS Executive with minor modifications made at execution time to permit automatic switch-over between processors. The TDOS Executive permits multiprogramming in the background while CLETS is operational.

Eight distinct line programs are required for the eight types of hardware interfaces in the system. These interfaces are as follows:

(a) Model 33/35 teletypewriter operating as a dial terminal through a 400 Data Pack or 757A Line Switcher.

(b) Model 35 teletypewriter operating as a controlled terminal on an 8A1 circuit.

(c) Model 28 teletypewriter operating as a controlled terminal on an 83B3 circuit.

(d) Model 28 Receiver-only teletypewriter operating as an uncontrolled terminal on a bulletin network line.

(e) Department of Motor Vehicles RCA Spectra 70/45 utilizing three 2400 bps lines.

(f) Center-to-center utilizing two 2400 bps line pairs operating as two full duplex lines.

(g) CLETS computer-to-local agency computer utilizing 2400 bps lines.

(h) National Crime Information Center utilizing three 2400 bps lines.

The low speed terminals are configured in a variety of ways; multi-station controlled lines, station operating several terminals as dial rotaries or controlled rotaries, and stations operating two terminals with seperate send and receive facilities.

The interfaces to the other computer systems are all programmed using poll, call, and acknowledge logic. Intercenter and intercomputer message transmission employs a highly efficient, free-wheeling logic with no acknowledgement required between messages.

Message segments are recorded as they arrive along with their corresponding journals. Segments are forward linked with

the linkage occurring after the segments are recorded. All incoming data is recorded twice on disc for back-up and a third time on tape for off-line statistical processing and for a possible second level fall back retrieval.

Multiple addressing and group code addressing permit addressing up to sixty stations for each message. Queueing to stations (including other computers) is performed by priority. Traffic for circuits on intercept may be alternately routed, or held indefinitely. When the station or line can again accept traffic, the operator at the monitor may elect to re-enter intercepted traffic or to deliver it off line.

The programmable hardware switching capability permits removal and re-entry of individual system components (disc, tape, controller) in case of failure of for preventive maintenance. Three monitor terminals at each center are used operator control. Operator commands permit control of the network and of the computor equipment.

C. PACIFIC TELEPHONE 400 DATA PACKAGE SYSTEM (400 DATA PACK)

The 400 Data Pack was specially designed as an auxiliary switching unit and port concentrator for computers used in information systems. It is a four-wire cross-bar common control switching machine and is expandable in ten port modules to a maximum of 60 ports. A complete basic system consisting of common control equipment, power supply, and cross-bar switches for 20 ports is housed in a cabinet 27 1/4 inches wide by 30 1/8 inches deep by 63 5/8 inches high. An additional cabinet is required for systems with more than 20 ports. Each complete cabinet weighs approximately 900 pounds.

The 400 Data Pack has several features which make it particularly desireable for law enforcement data communications. Most significant of these are the following:

Once the common control unit has established the connection for the communication channel, the 400 Data Pack is insensitive to the language, code, format or (within limits) the speed of transmission.

Class marks are available to segregate five different types of traffic. These class marks define which ports can or cannot be connected to each other. For example, class marks could be used to restrict certain ports from gaining access to a port connected to a specific computer data base.

The cross-bar switching equipment is extremely reliable. The first 400 Data Pack was installed in 1967 and, by the end of 1973, over 40 were in operation throughout the State. To date, these switchers have been operating 24 hours a day without a single failure.

Other significant features include the ability to multiple address up to six ports simultaneously, Touch-Tone selection with an average connect time of three to five seconds, and retry feature. The retry circuitry in the common control unit stores the number of the called port and continuously attempts to complete the call for a specified period of time if the called port is busy. If the called port becomes idle during the retry period, the connection between the called port and the calling port will be made without any additional action being required of the calling port operator.

The 400 Data Pack does, however, have certain limitations which cannot be exceeded:

No more than ten connections can be made within the switcher at one time.

Although the 400 Data Pack is insensitive to signals sent through it, any terminal connected to its ports in limited to voice bandwidth (2400bps).

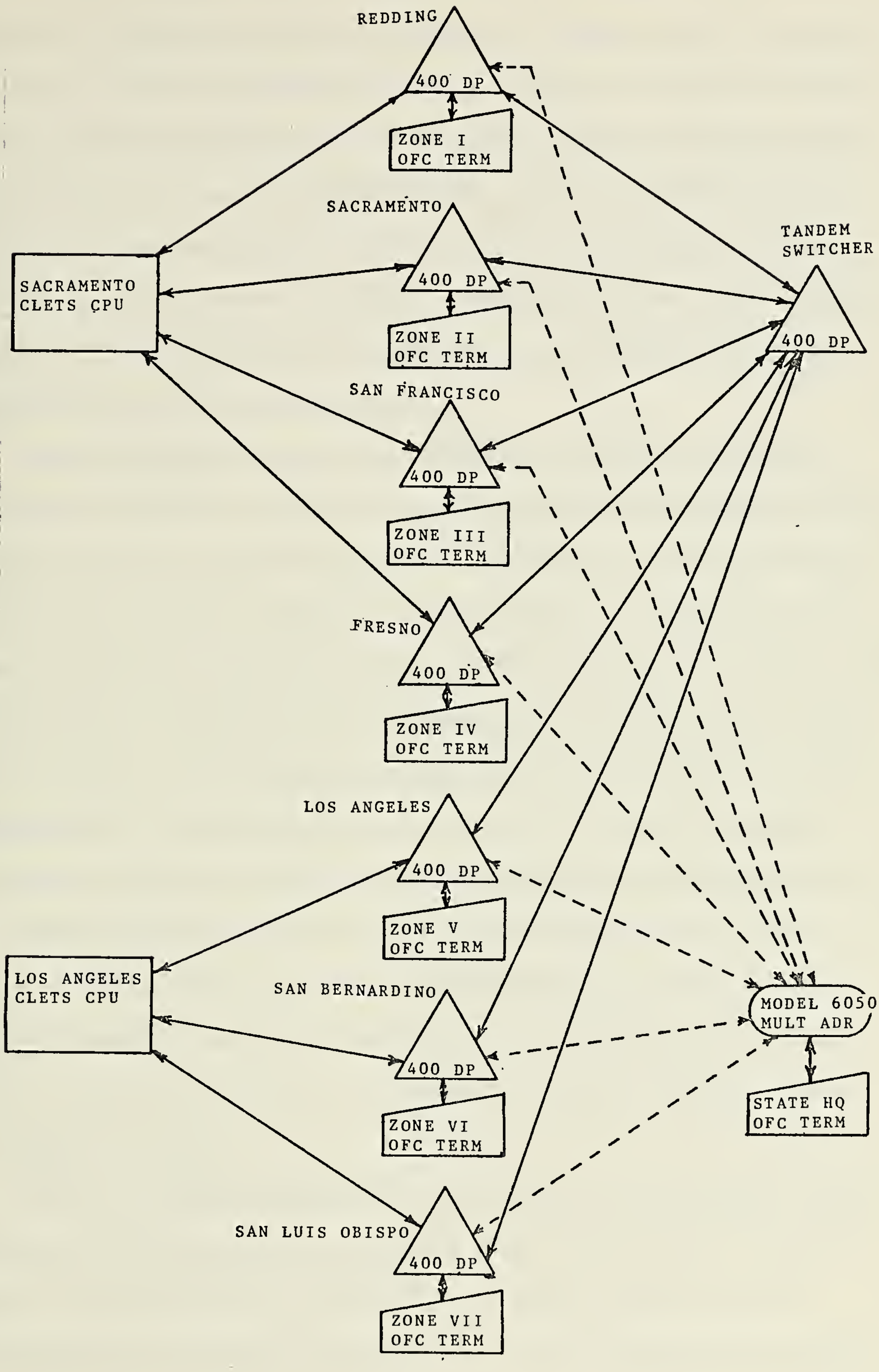
Any terminal connected to a 400 Data Pack port must be equipped with Touch-Tone dialing in order to communicate with the common control unit and establish connections to other ports.

D. PATROL'S AUTOMATIC TELECOMMUNICATIONS RAPID ON-LINE SYSTEM (PATROLS)

The CHP telecommunications system, PATROLS, fig. II.2, consists of eight 400 Data Pack systems, a Model 6050 multiple address key, Model 28, 33, and 35 teletypewriters as terminals, and voice grade lines, all of which are leased from Pacific Telephone Company. Seven of the 400 Data Packs are assigned to the seven zones of the CHP and the eighth is used as a "tandem switcher" to provide a capability for calls between the various zones. The Model 6050 multiple address key is used to give the CHP Headquarters in Sacramento the capability of addressing terminals in different zones simultaneously.

The assignment of the 400 Data Packs by zones was based on the CHP line organization and has nothing to do with network loading. The switchers are all collocated with the Zone Headquarters except for the Zone II switcher which is collocated with State Headquarters and the Zone VI switcher which is located in the San Bernardino area office.

PATROLS NETWORK FIGURE II.2



The PATROLS network does not utilize the administrative network feature of CLETS for station-to-station or multiple address message routing. (This arrangement is the result of the fact that PATROLS was not designed specifically for use with CLETS.) Messages which are addressed to users terminated with other switches are routed through the tandem switcher located in Fresno. Individual users have such an infrequent demand for a multiple address capability that while such a capability may technically exist, it is not procedurally addressed in system documentation.

State Headquarters has the capability to address messages to multiple recipients in different zones through the Model 6050 multiple address key but his feature is seldom employed. In order to send a message to multiple recipients simultaneously, a "conference net" must be established with all of the recipients on the line at once. The procedure for using this multiple addressing capability requires that the terminals of all addresses be idle before the "conference net" is established. Also, addressees cannot send or receive any other messages until the "conference net" is terminated by Headquarters.

The "class marks" feature of the 400 Data Pack is used to divide terminal users into classes based upon their primary role as dispatch center or administrative user. The class marks are not used to isolate the classes but to guarantee higher line availability to dispatch centers.

There are thirty dispatch centers in the state distributed in such a manner that there are no more than five in any one zone. Each zone's 400 Data Pack is connected to a CLETS CPU by a trunk containing between three and nine lines. Two or three of these lines

are classed so that only dispatch centers can access them. The remaining lines in the trunk are classed so that they can be accessed by the 101 administrative users in the network.

Ten administrative users also have "Receive Only" terminals which are used to receive overflow incoming messages which are addressed to a companion Automatic Send Receive machine or to the "Receive Only" machine. These machines are located only in those offices which have a heavy volume of incoming message traffic, generally Zone and State Headquarters.

With the exception of overflow routing to the "Receive Only" machines described above, all message routing on PATROLS is a manual operation. The operator at the originating terminal dials the receiving terminal either directly or through the tandem switcher. If the receiving terminal is busy, the retry circuitry in the common controller will automatically continue attempting the call. There is not, however, any alternate route selection or store and forward capability.

In summary, the existing PATROLS system is organized to follow the CHP line organization. It is really two different systems which share common lines and terminals. One system is a high speed law enforcement data system and the other is an administrative teletypewriter network like TWX or TELEX. A well planned analysis of PATROLS could result in a thorough understanding of the telecommunications needs of CHP as well as providing the data necessary for an analytical system design.

III. ANALYSIS OF TELECOMMUNICATIONS SYSTEM REQUIREMENTS

The PATROLS system uses terminals operating at speeds of 100 words per minute. Messages are transmitted over the lines in the eight-level ASCII code at a rate of 110 bps. The use of lines which are capable of carrying 2400 bps to carry PATROLS traffic at 110 bps appears to be inefficient. Analysis of the entire PATROLS system could reveal the efficicncy of the entire system and indicate those areas in which improvements would produce the greatest increase in system efficiency. The remainder of this chapter is devoted to discussing those aspects of communications network system analysis which are applicable to a study of PATROLS.

A. DETERMINATION OF TRAFFIC VOLUMES

There are three different types or classes of messages in the PATROLS system. These classes are the CLETS inquiry, the CLETS reply, and the administrative message. The raw data required for an analysis of the system would include the type or class of message, the time of transmission or receipt, the source or destination, and the length of the message.

From the raw data described above, it would be possible to determine when the network peak loads occur; the time distribution of messages in the system, by class as well as cumulative; the mean and variance of message lengths, as well as other statistics. These statistics would then form the basis of calculations concerning the network analysis including network layout, terminal operating speeds,

and network queues. Also, the correlation between non-communications operations and network loading could be determined. These various statistics could then be used for predicting future communications requirements for various non-communications activity configurations.

The required data concerning CLETS inquiries and responses is available in the CLETS CPU as a part of the internal accounting routine. However, CLETS records are intended to reveal utilization data by specific data base rather than by subscriber. Therefore, a CLETS software change would be required to extract only that data pertaining to CHP utilization of CLETS, regardless of the data base utilized. For administrative messages there are no terminal files maintained for the purpose of data collection. A simple station log could be designed and utilized to collect the required data with minimal additional effort by the terminal operator. For example, recording the length of the message in lines vice characters would be sufficiently accurate if a preliminary analysis indicated that administrative messages consisted of an approximately constant number of characters per line.

B. DETERMINATION OF NETWORK RESPONSE TIME REQUIREMENTS

Martin [2] defines response time as follows:

> "...the time the system takes to react to a given input. If a message is keyed into a terminal by an operator and the reply from the computer, when it comes, is typed at the same terminal, response time may be defined as the time interval between the operator pressing the last key and the terminal typing the first letter of the reply. ...it is the interval between an event and the system's response to the event."

Response time therefore is not applicable to administrative traffic, but only to CLETS messages. Communications with CLETS

are not conversational in the sense of several exchanges between the operator and the computer, but normally involve one inquiry and one response per transaction. The only general exception to this would be the case of checking the license number of an automobile and the driver of that same automobile. However, this procedure is not commonly employed by patrolmen in the field.

The dispatcher serving as the interface between the field unit and CLETS has other duties in addition to operating the teletype. The response time, therefore, should not be so great as to unnecessarily require the dispatcher's attention. The system response time specified in [5] is ten seconds. That system, however, does not perform all of the functions of PATROLS so that ten second figure may not be appropriate in PATROLS applications. Because the response time of the PATROLS network is actually limited by CLETS, present and future capabilities of CLETS must be considered.

C. DETERMINATION OF TERMINAL CHARACTERISTICS

Administrative messages and CLETS messages are handled differently at the user's end, thus dictating certain terminal characteristics. The presently used Model 33 and 35 Teletypewriters are impact printers with a maximum print rate of ten characters per second. The operator has the option of sending data at his typing rate or pre-punching the message on paper tape and then sending it at the line rate of 100 wpm.

Characteristics for CRT terminals to be used in the Los Angeles Communications Center, primarily for CLETS communications are specified in [5]. These terminals are to be used in conjunction with a system consisting of a CPU/terminal controller, magnetic tape

drives, disc drives, and line printers; none of which are part of the existing PATROLS system. The specifications are, however, representative of existing CHP terminal requirements philosophy. Specific minimum characteristics listed are as follows:

- Minimum screen capacity of 1920 characters.
- Transmission rate switch selectable up to 9600 bps.
- Split screen capability and capable of displaying both variable and protected fixed data fields.
- Keyboard capable of installation remote from the screen, silent operating and full 64 ASCII character set.
- Terminal shall have full cursor control capability.
- Character display capable of normal, reversed video and blinking modes of operation.

Consideration of general terminal characteristics, in conjunction with the above specifications will aid in the determination of the most effective system terminal. Those characteristics to be considered are hard vs. soft copy output, terminal speed, amount of data that can be displayed, the type of data to be displayed and the character sets to be used, requirement for alert indicatiors and operator modification of data.

The LACC system specifies softcopy only for the CRT terminals with line printers available to produce a hard copy from system storage as required. The approach is satisfactory for CLETS messages but not necessarily for administrative messages, especially if the recall from storage is a lengthy or complicated procedure. Also, as PATROLS is presently configured, there is no storage capacity in the system. Therefore, a CRT terminal would be acceptable to the existing system only if it worked in conjunction with a line printer

or a dry-copy reproducer. The hard-copy requirements for administrative messages and for record keeping purposes must be considered in the determination of desired terminal characteristics.

Terminal speed is the limiting factor on system speed in PATROLS as the system is presently configured. Unless storage is provided in the terminal or some buffering technique is employed, this will always be the case. Therefore, if data analysis indicates a higher network operating speed than 100 wpm, the terminal selected must be capable of this higher network speed or a buffer must be added between the terminal and the network.

The amount of data which can be displayed is a parameter applicable only to CRT terminals. This type of terminal is capable of displaying only so many characters and messages which contain more than that number of characters require special handling procedures. The terminal may have internal storage which enables it to receive messages several pages long and display them one page at a time or the terminal controller/CPU may provide this feature. Alternatively, message length could be limited by administrative policy. Any message with a length greater than this limit would necessarily be transmitted in parts.

In the case of PATROLS, only alphanumeric data is transmitted and displayed. There are no requirements for an ability to reproduce invoice forms, histograms or the like. Should this capability be desired, however, it must be recognized that not all CRT terminals have this capability and the choices will be necessarily limited.

Analysis of network operating procedures indicate that several situations necessitate the use of alert indicators such as bells or

flashing displays. The administrative operator is normally a secretary or, possibly, a patrolman who has responsibilities other than sitting in front of the terminal waiting for messages to process. If the terminal is an impact-type printer, the operation of the printer is noisy enough to attract the attention of the operator. A CRT terminal or a non-impact printer is virtually noiseless and an audible alarm would be required to attract the attention of the operator. Also, an alarm indicator would be important to signify the arrival of a message containing information of a vital or critical nature. In the case of the CLETS operator, the audible alarm is not necessary to indicate the arrival of a message, but the alarm could be used to indicate the presence of critical data, such as "armed and dangerous," which must be passed to the officer in the field.

The ability of the operator to modify or edit data after it has been typed or keyed into the terminal may not affect network performance but may improve organizational performance. With the Model 33/35 teletypewriters the operator may edit data after it is typed only if he is using the punched paper tape feature. If he is typing on line, and it is a formatted message such as a CLETS inquiry, he must negate and restart the message. Regardless of the operator proficiency on the keyboard, the ability to edit messages after they are entered into the terminal will increase his efficiency which is especially significant if the terminal is to be used for administrative traffic.

D. DETERMINATION OF TERMINAL DISTRIBUTION AMONG USERS

The number of terminals assigned to a particular user or location is determined by the message load which it experiences and its

particular function. The Los Angeles Communications Center may be identified as a single user but CHP has determined that 23 CRT terminals are required at this one location (see [5]).

The CHP should specify the absolute minimum acceptable capability of each location (usually one send/receive terminal), but analytical computations will determine the number required to meet the individual requirements of each location. This can be done by determining the message load of the location, the speed at which the system communicates data, and the characteristics of the terminals to be employed.

E. DETERMINATION OF NETWORK ORGANIZATION AND TERMINAL CONTROL

The existing PATROLS system utilizes line switching through a private exchange - the 400 Data Package. This arrangement affords certain economies by reducing total network line mileage and costs while providing high reliability. Achievement of these economies, however, necessitates certain system compromises. There are currently seven 400 Data Packs in the system accomodating 142 terminals. However, due to the design constraints of the 400 Data Pack switcher, only 70 connections can be made at any one time. (The actual number of connections which can be made may be less due to the use of the class marks feature.) Also, it takes from three to five seconds to establish a connection through the 400 Data Pack before any data can be transmitted. In the case of very brief CLETS inquiries, it may require longer to establish the connection between the user and CLETS than to transmit the message. Finally, the total system line length is still significant because each terminal requires a seperate line to connect it to the 400 Data Pack.

The use of multidrop lines can reduce total network line length and, at the same time, possibly decrease network waiting time. In the case of multidrop lines, several terminals are on the same line and only one terminal can transmit or receive at one time. Each terminal is more complex in that it must possess the capability to recognize its own address so that it only transmits or receives traffic for that address. This system normally includes a processor which controls the network and determines when the various terminals on that line are allowed to transmit or receive.

The terminal or network controller must regulate the traffic flow on the line if any data is to be passed. There are several approaches to this function, all of which reduce to either a contention queue or a polling scheme.

Whenever more than one terminal on a multidrop line desires to use that line at the same time, a waiting line or queue develops. In order to analyze network performance, it is necessary to determine statistics regarding message time in the queue and the probability that a particular line will be in use when it is required. Queuing calculations necessary to analyze a multidrop network, including such additional factors as priorities and interrupts are discussed in [2]. The essential system statistics required to perform these calculations are the numbers and lengths of messages handled by the system and the distribution of message transactions over a given period of time.

An alternative to a contention queue as a form of line control is the use of a polling scheme. In a polled line, the line controller interrogates the terminals on the line to determine if they have messages to send and directs that they send their traffic when the network is available.

The most common form of polling is "roll-call" where a polling list is established in the controller and the controller simply follows the list in allocating network time to the various terminals. A terminal which handles more traffic than others may appear more than once on the polling list in order to afford it the opportunity to handle all of its traffic. Alternatively, the list may be arranged by order of priority and at the end of each transaction the controller would recycle to the beginning of the list rather than continuing to the next terminal on the list.

Regardless of the multidrop control technique employed, the terminals with data to communicate must be ready when their turn comes. This readiness can be assured by the use of a buffer in the terminal. The existing system uses punched paper tape while most CRT terminals use core memory to store the message until it is ready for transmission. In both cases the message is sent at a much higher rate than the one at which it was prepared.

Another method of reducing total network line length is by multiplexing. Buffers are used to transmit a single message at rates up to the maximum speed of the line, while multiplexing provides a means of sending several messages over the same line simultaneously. There are two basic types of multiplexing available for use on telephone networks: Frequency-division and time-division.

Frequency-division multiplex (FDM) is a technique whereby one line with a given channel capacity is sub-divided into several slower channels. The sum of the slower channel capacities is less than the original capacity because there must be capacity between the channels left unused in order to prevent interference between the channels.

Also, those frequencies used by the Bell System for signalling cannot be used for data transmission. In spite of this apparent reduction in line capacity, FDM does in fact provide an efficient means of increasing network availability to slower terminals by effectively giving each terminal a private line.

Time-division multiplexing (TDM) is a more complicated technique in which the lines from the terminals are sampled in a round-robin fashion and the signal present in the sample is transmitted as a discrete signal. The sampling rate is sufficiently high to allow each terminal to be sampled before it receives the next bit of information. For example, a line carrying data at 100 bps receives a new bit every ten milliseconds. If ten such lines were to be TDM multiplexed on to one line, the sampling rate used must be at least 1000 bps for all lines to be sampled. The resulting bit stream is transmitted at the sampling rate to an identical unit serving as a receiver or demultiplexer. The demultiplexer divides the data stream into its component signals and sends them out on their respective lines. The multiplexers at the sending and receiving ends of the lines must maintain synchronous operation if the data is to remain on the proper channels. For example, if the receive-end unit were to fall one bit behind the send unit, channel two would receive channel one data, etc. Normally, a clock or synchronizing bit is sent along with the data stream to prevent such an occurance.

Regardless of the multiplexing scheme employed, each possesses certain advantages over other methods of improving line utilization.

1. They are relatively inexpensive, much cheaper than concentrators and the sophisticated terminals required in a multidrop polled network.

2. Multiplexors do not alter the data being carried on the lines in any way - they are "transparent."

3. Because of their simplicity, they are normally very reliable devices.

4. Terminals are always connected and are never required to wait for an available line as they must in the case of a private exchange or a contention polling network.

The most significant drawback to using multiplexors in PATROLS is the fact that each terminal would effectively be "hard-wired" to one line. If that line terminated with CLETS there would be no problem with CLETS traffic. However, administrative traffic would be required to use the CLETS Administrative Network and the impact of such a load increase would have to be determined prior to its implementation. Also, CLETS has a limited number of input/output channels available and the number of channels allocated to CHP would have to equal the number of terminals in the CHP network. Therefore, the employment of multiplexors is dependent upon CLETS I/O channel availability.

The final method of network organization and control to be discussed is the "hold and forward" concentrator. As the name implies, these devices utilize a storage capacity to hold and retransmit messages. Additionally, these devices may be used to perform record-keeping functions for the network, restructure the format or content of messages, and control terminals. The concentrator is, then a computer which may either be a special application configuration or application independent. The CLETS UNIVAC Spectra 70/46 computers have a special application configuration.

An alternative to this expensive, complex arrangement is the application independent concentrator. This concentrator will generally perform the following functions:

1. Buffering: Messages incoming from low speed terminals are stored before any other manipulation takes place. Similarly, outgoing traffic to low speed terminals is read out of memory at the terminal operating speed.

2. Allocation of Storage and Control of Queues: Messages awaiting transmission must be stored and the concentrator must be capable of determining which storage areas are occupied and which are available. Also, the concentrator must have the capability of linking the various messages in storage so that the entire contents of the queue is transmitted at the proper time.

3. Receipt of Messages on the Low Speed Lines: The concentrator must continuously sample all incoming lines so as to receive and store incoming messages without delay. Also, the concentrator must be capable of receiving messages from terminals using different codes and/or operating at different speeds.

4. Code Translation: The high speed line may be operating in a synchronous mode of operation while the low speed terminals operate in the asynchronous or start-stop mode. The concentrator must be capable of interfacing the two modes.

5. Polling and Network Control: The concentrator must be capable of implementing the polling and line control procedures which are designed into the system.

In summary, no particular terminal or network organization or response time can be specified without first determining the actual requirements of the user. Once this determination is made, various systems analysis techniques can be applied to assure the development of a communication system capable of meeting all user needs.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The existing PATROLS network follows CHP line organization. This is unnecessary and probably ineffective. The sole criteria for network organizations should be maximizing service while minimizing costs. An analysis of system loading and user requirements is the most effective means of designing a telecommunications network.

Attempting to combine a real-time data retrieval system and a narrative communications network is difficult for several reasons. Their methods of employment are not the same, nor are their measures of performance. The real time information requirements of patrolmen in the field are best served by a system with a rapid response time. The primary concern of the administrative user is not with response time, but with the quantity of data the system is capable of handling. In order to satisfy the mission of the CHP, the needs of the patrolman in the field must be served first. Other users must tailor their requirements so as not to detract from the efficiency of the patrolman's network.

The primary controlling element of CHP data communications is CLETS. CLETS dictates message format, minimum response time and message priorities. A thorough knowledge of CLETS, as well as an understanding of the philosophy behind its development, is necessary to develop a truly compatable system.

Finally, line switching with a private exchange is not optimal for CHP communications. No additional benefit is gained from adding

lines to this system since only ten connections are currently possible with the existing switcher. Althorough analysis will result in a system which can better satisfy user requirements and, concurrently make the users more aware of their actual requirements.

B. RECOMMENDATIONS

Martin [2] describes 16 steps in the design of a teleprocessing network, and these 16 steps are arranged as an algoritmic flowchart in figure IV.1. By systematically following the steps in this flow-chart, an effective system for CHP data communications can be designed.

The following discussion of the steps in the flow-chart is intended to provide guidance and interpretation for its implementation.

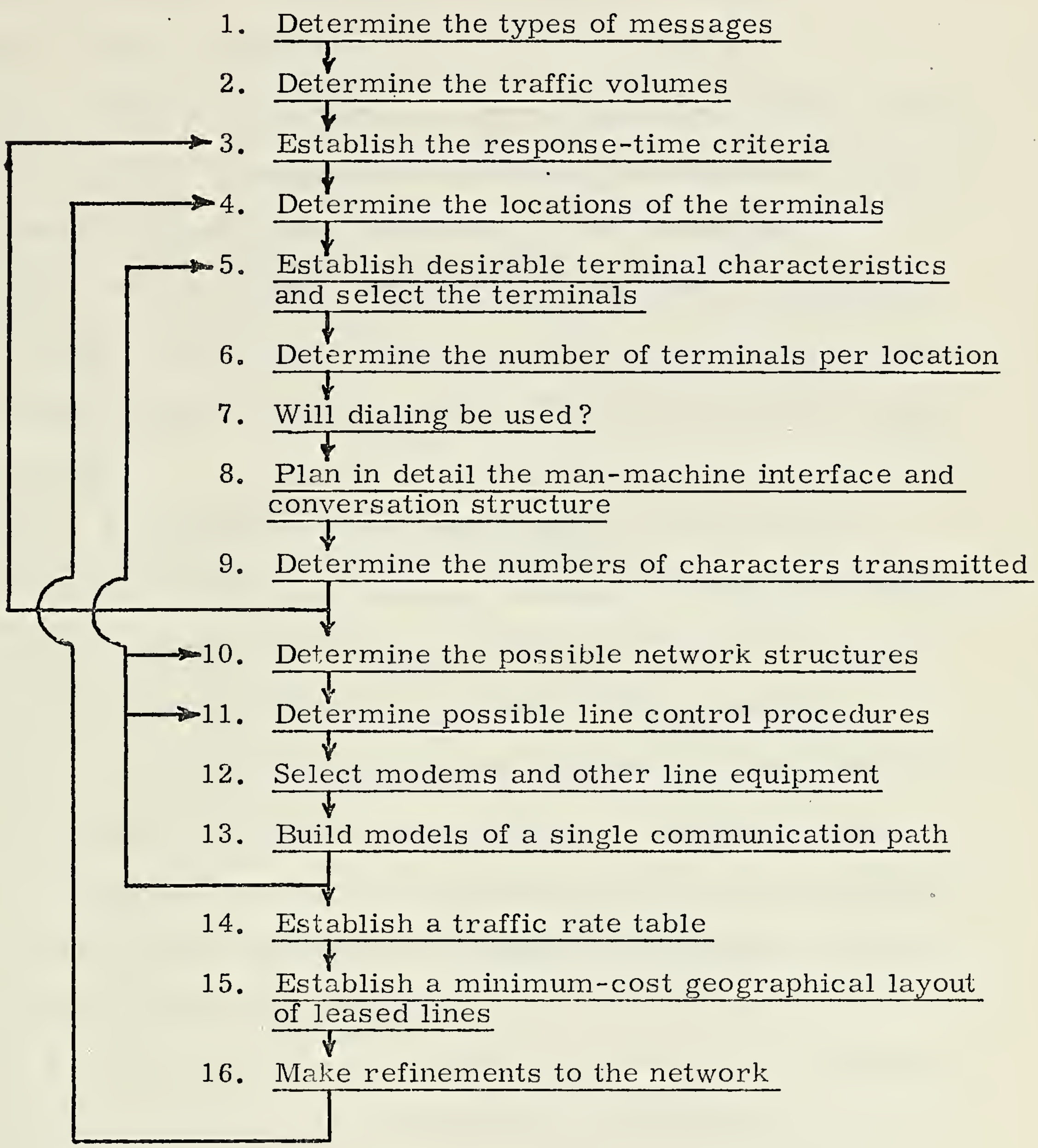
Step 1: Part III. A of this thesis describes the three types of messages which are presently transmitted in the PATROLS network. Any future changes in the type of messages being transmitted would require additional design effort. Particular attention should be paid to the possibility that the Data Processing Section may propose to use a future network for the handling of data (payroll, etc.) presently mailed to Sacramento and key punched at State Headquarters.

Step 2: The determination of traffic volumes is discussed in Part III. A. Completion of this step would involve design and implementation of a log for data collection and a software change for data retrieval from the CLETS CPU's.

Step 3: Determination of the response time criteria is discussed in Part III. B. Additional information in the form of definitive statements of requirements from CHP and of constraints from CLETS is required for this determination.

STEPS IN THE DESIGN OF A TELEPROCESSING NETWORK[1]

Figure IV.1



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[1] Adapted from Martin [2]

Step 4: The allocation of terminals, which is basically a policy decision of CHP, is discussed in Part III. D. However, the policy statement should be in terms of minimum service required, not numbers or types of terminals.

Step 5: Part III. C introduces some of the desirable characteristics of CRT terminals. Completion of this step should include a consideration of line and page printers in addition to CRT terminals.

Step 6: The distribution of terminals among users is discussed in Part III. D. The actual determination of the number of terminals per location, however, cannot be made until the preceding five steps are completed.

Step 7: In Part III. E of this thesis, the 400 Data Package, a private exchange used in the existing PATROLS network is discussed. Data collected in the completion of steps one and two should be used to make the calculations described by Martin [2, chapter 33] .

Step 8: The conversation structure is pre-defined by CLETS and is not considered as a variable in the system. The man-machine interface design is therefore constrained by the physical arrangement of the terminals and, if "hold and forward" concentrators are used, by the software of the concentrator.

Step 9: The number of characters transmitted will be determined during step two. However, if a "hold and forward" concentrator is chosen another alternative will exist. If the concentrator and terminals are so programmed, only the variable data in the message field may be transmitted. Therefore, this decision depends upon the choices made in steps ten and eleven.

Step 10: The determination of possible network structures is discussed in Part III. E. In particular, multiplexers, private exchanges, "hold and forward" concentrators are discussed.

Step 11: Various possible line control procedures, such as queueing, polling and line controllers are discussed in Part III. E.

Step 12: Martin [2, 3] discusses the various modems available for employment in the system under consideration. Also, various trade journals and vendors are a source of information concerning equipment capabilities and availability. It is not, however, the purpose of this thesis or this recommended design procedure to specify a particular equipment or vendor. Instead, application of this thesis and its recommendations should result in a system design and specifications which may be presented to vendors as part of an Invitation For Bid. Also, it will provide a mechanism for measuring the performance of various vendors in submitting responsive bids.

Step 13: Martin [2] presents a detailed discussion of the applications of simulation to the communication system. A well designed model and reliable data are absolute requirements for the design process. He discusses the use of computerized models in both FORTRAN and PL/1 as well as an extensive discussion of the use of IBM's General Purpose System's Simulator, GPSS.

Step 14: A traffic rate table is a compilation of the maximum allowable load for a line. In the case of multi-drop lines, the table usually relates the numbers of messages the line is capable of carrying to the number of terminals on the line. The traffic rate may be presented graphically as response time versus message throughput

or as the probability that response time does not exceed a given value versus response time in seconds.

Step 15: Williams and Esau [6] develop an iterative method for determining an optimal geographic configuration for a network, where minimum line length is equivalent to minimum cost and accurate network traffic rates are available. The only additional information which would be required for using this method is the V and H coordinates for each terminal as listed in USA Tariff, FCC #255, filed by American Telephone and Telegraph Company. These coordinates for all CHP terminals have been compiled by the author but are not included in this thesis because it is felt that they would not make a significant contribution but only serve as filler.[2]

Step 16: Since the entire system design process is an iterative one, several iterations will be required to arrive at the final design. At each iteration, the sensitivity of the variables must be measured. This sensitivity analysis will determine those variables which have the greatest impact on overall network performance. These critical variables should then be used as benchmarks against which various growth requirements can be measured.

Finally, Martin [2] discusses his "Parkinson's Law of Real-Time Systems" in which he states:

> "If operator terminals provide a useful service, their utilization will expand to fill the system capacity."

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[2] The coordinates for all CHP terminals are available from Prof. S. H. Parry.

The very nature of real time systems dictates that they be responsive to changing user requirements and the evolution of technology. Thus, it is imperative that the execution of the design steps discussed herein include the capability of providing various statistics on current system operations. It is hoped that the system specifications, identification of problem areas, and system design procedures described in this thesis will provide the impetus for future analysis of the complexities of the growing CHP communications system.

APPENDIX A

GLOSSARY OF TERMS & ABBREVIATIONS

ADDRESS: A coded representation of the destination of data, or of their originating terminal.

ALTERNATE ROUTING: An alternative communications path used if the normal one is not available.

ASCII (American Standard Code for Information Interchange): An eight-level code for data transfer adopted by the American Standards Association to achieve compatibility between data devices.

ASYNCHRONOUS TRANSMISSION: Transmission in which each information character, or sometimes each word or small block, is individually synchronized, usually by the use of start and stop elements.

BIT: Contraction of "binary digit," the smallest unit of information in a binary system.

BIT RATE: The speed at which bits are transmitted, usually expressed in bits per second (bps).

BUFFER: A storage device used to compensate for a difference in rate of data flow, or time of occurrence of events, when transmitting data from one device to another.

CHANNEL: A path for electrical transmission between two or more points without common-carrier-provided terminal equipment. Also called circuit, line, link, path, or facility.

CHP: California Highway Patrol

CIRCUIT, FOUR-WIRE: A communication path in which four wires (two for each direction of transmission) are presented to the station equipment.

CLETS: California Law Enforcement Telecommunications System.

CONTENTION: This is a method of line control in which the terminals request to transmit. If the channel in question is free, transmission goes ahead; if it is not free, the terminal will have to wait until it becomes free. The queue of contention requests may be built up by the computer, and this can either be in a prearranged sequence or in the sequence in which the requests are made.

CROSS-BAR SWITCH: A switch having a plurality of vertical paths, a plurality of horizontal paths, and electromagentically operated mechanical means for interconnecting any one of the horizontal paths.

FCC: Federal Communications Commission.

FREQUENCY-DIVISION MULTIPLEX: A multiplex system in which the available transmission frequency range is divided into narrower bands, each used for a separate channel.

LINE SWITCHING: Switching in which a circuit path is set up between the incoming and outgoing lines.

MESSAGE SWITCHING: The technique of receiving a message, storing it until the proper outgoing line is available, and then retransmitting. No direct connection between the incoming and outgoing lines is set up as in line switching.

MULTIDROP LINE: Line or circuit interconnecting several stations.

MULTIPLEXING: The division of a transmission facility into two or more channels either by splitting the frequency band transmitted by the channel into narrower bands, each of which is used to constitute a distinct channel (frequency-division multiplex), or by allotting this common channel to several different information channels, one at a time (time-division multiplex).

RCA TDOS: RCA Tape/Disc Operating System for the Spectra 70 series digital computer. A magnetic tape resident operating system that can control up to six independent programs. Provides: (1) support for mass storage devices; (2) more efficient operation through use of discs as library storage media; and (3) a modular software system designed to operate under control of the TDOS Executive and facilitate the implementation of a data communications system.

RESPONSE TIME: This is the time the system takes to react to a given input. If a message is keyed into a terminal by an operator and the reply from the computer, when it comes, is typed at the same terminal, response time may be defined as the time interval between the operator pressing the last key and the terminal typing the first letter of the reply. For different types of terminal, response time may be defined similarly. It is the interval between an event and the system's response to the event.

STORE AND FORWARD: The interruption of data flow from the originating terminal to the designated receiver by storing the information enroute and forwarding it at a later time.

SYNCHRONOUS TRANSMISSION: A transmission process such that between any two significant instants there is always an integral number of unit intervals. Contrast with ASYNCHRONOUS TRANSMISSION.

TERMINAL: Any device capable of sending and/or receiving information over a communication channel.

TIME-DIVISION MULTIPLEX: A system in which a channel is established in connecting intermittently, generally at regular intervals and by means of an automatic distribution, its terminal equipment to a common channel. At times when these connections are not established, the section of the common channel between the distributors can be utilized in order to establish other similar channels, in turn.

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